December 30, 2004

Federal Communications Commission
445 12th Street SW
Washington, DC 20554

Comments RE: WT Docket No. 04-344; RM-10821; FCC 04-207 (Proposed Rule on Maritime Communications, as Published in the Federal Register on November 15, 2004)

RF Neulink appreciates the opportunity to respond to FCC on the following issues. Our interest exists mainly with our comment and clarification of issues raised in the FCC's current AIS Notice of Proposed Rule Making. Along with our comments on the Commissions tenitive conclusions, we have also provided an alternative technical solution that we believe more effectively facilitates the use of Channels 87B and 88B for AIS use in the United States.

It appears as if the FCC has taken the position of defending the interferer while trivializing the concerns of radio channel license holders. We believe the FCC has not taken all reasonable measures to ensure that such systems will neither cause nor receive harmful interference to or from other authorized users when placed in their intended operational environments.

The FCC's complacency in protecting Maritel from channel interference caused by another government agency is alarming. We believe that Maritel represents a far greater issue than just that of their individual concern. This impacts all Americans that intend to purchase and operate licensed spectrum in the future. Maritel has spent millions of dollars in obtaining this spectrum for providing wireless data services to the marine community. The success of their business will be determined by the quality of service they provide to their customers.

We have found the comments in the JSC report that concluded, "the use of Forward Error Correction (FEC) and block interleaving in the modem will allow normal operation in the presence of AIS emissions" to be inaccurate in light of new test results included with this submittal. The use of FEC and block interleaving in radio channel data protocols are intended to extend the operating range of the system and improve overall data transaction reliability of the system. When this benefit is compromised in order to compensate for deliberate man made interference, it diminishes the effect of it's intended purpose. For these reasons, as discussed more fully below, we conclude that FEC and block interleaving is not an effective engineering solution to mitigate AIS interference.

In spite of FCC's attempts to underestimate the effects of AIS interference, the facts show channels proposed by the USCG to be used for AIS services cause co-channel and adjacent channel interference to MariTEL's licensed channels. This interference manifests itself in short periodic interference that causes persistent and residual disruption to the Maritel channels. At a minimum, this interference is of a short duration (28 ms) and causes long-term discontinuity of the intended transmitted information at the vessel receivers. This sudden discontinuity and disruption of the data stream requires specialized mitigation and avoidance of this interference in order to recover the channel information and ensure a level of reliable communications to it's users.

A critical area that was overlooked in the NTIA's analysis of AIS interference is transmitter noise and receiver desensitization. We will show interference resulting from AIS equipment operating within the frequency spectrum, under certain circumstances will cause a degraded communication channel.

As we well know, receiver desensitization results when a transmitter is operated in close proximity to a receiver that is tuned to a frequency that is close to the transmit frequency. We will show an AIS transmitter signal can overload the receiver front end, preventing data on the correct receive frequency from being correctly received regardless of FEC and block interleaving techniques. A reduction of the receivers effective sensitivity can be strongly influenced by outside RF noise, or the presence of a strong adjacent frequency such as AIS emissions.

Following are RF Neulink's comments on specific aspects of the Commissions tentative conclusions.

Data vs. Voice System Performance

The Commission's confusion between the results of the JSC and InCode report is easily explained. While RF Industries would typically not lecture the Commission on the fundamental differences between voice and data systems, the Commissions apparent misunderstanding of basic data system performance characteristics makes us believe the following may be useful.

The results of the JSC and InCode reports are complementary. The JSC report performs modeling and theoretical calculations of AIS interference to both voice and data systems. The JSC results are provided primarily as Bit-Error-Rate (BER) in various simulated conditions. While BER is potentially useful for some RF analysis, Packet-Error-Rate (PER) is a more relevant parameter for analyzing the performance of a data system. PER inherently considers channel conditions plus any error detection / correction techniques to give an accurate indication of the number of packets that must be re-transmitted. Data system performance is directly correlated and highly susceptible to PER. For these reasons the JSC theoretical analysis, provides insufficient insight into the impact of AIS interference within a wireless data system.

Incode's report takes the JSC theoretical modeling to the next logical step by testing the actual performance impact of AIS interference to a commercially available wireless data system[1]. InCode's tests focuses on the actual system impact of AIS interference based on varying power levels and spectrum proximity. The results show the direct impact of losing and retransmitting packets in a wireless data system. Incode's test results showing a 50% system loss is a reasonable conclusion for the tested environment considering the impact of

[1] InCode report used FCC type accepted, commercially available NL 6000's manufactured and marketed by RFNeulink and a type accepted AIS transmitter.

packet re-transmissions. Further, under these conditions, the system is expected to be very unstable.

We conclude that the InCode report adequately represents the expected performance degradation of a wireless data system when packet loss and re-transmission is occurring regularly. Conversely, we find nothing technically substantive in the JSC report that addresses this overriding consideration. The JSC analysis simply does not go far enough to model or test the impact of AIS within an actual wireless data system, therefore their recommended solutions are premature.

FEC Codes / Interleaving

The Commission's conclusions are based seemingly on comments by the NTIA, in that users of the VPC band have the ability "to incorporate FEC codes and block interleaving to prevent interference to VPC data transmissions[2]", however, the Commission nor the NTIA provides technical justification for this assertion[3]. The NTIA's comments instead rely on circumstantial evidence and innuendos to conclude that "current state-of-the-art in digital radio communications provides mitigation techniques that would provide adequate protection against this potential AIS interference to MariTEL's proposed data services"[4].

The Commissions' tentative conclusion on AIS interference was of particular interest to RF Neulink because of our desire to enter the maritime market and our existing state-of-the-art radio designs. We particularly saw an opportunity based on the the JSC's proposed FEC code / Block interleaving solution to quickly develop a device to overcome AIS interference. Toward that end, RF Industries re-engaged Dorr Engineering, the designer of our state-of-the-art radios, to develop and test our existing radio designs plus develop a prototype of the JSC suggested solution.

The result of the testing by Dorr Engineering is attached. The results show that neither the current design of the NL6000 nor the JSC suggest FEC Code and Block Interleaver combination prevented AIS interference. The general engineering conclusion is that FEC / Interleaving techniques are not an effective engineering solution to mitigate AIS interference. Even after losing 50-70% of the channel capacity to error correcting coding[5], this scheme simply does not work. The reports conclusion underscores the need to either: 1) Minimize the AIS power input into the data receiver through antenna separation or filtering techniques or 2) Develop new unique technology that specifically mitigates the characteristics of AIS interference.

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[2] Amendment of the Commission's Rules Regarding Maritime Automatic Identification Systems; Petition for Rule Making Filed by National Telecommunications and Information Administration; Emergency Petition for Declaratory Ruling Filed by MariTEL, Inc., WT Docket No. 04-344, RM-10821, FCC 04-207, ¶ 47 (refered to as AIS NPRM)

[3] RF Neulink finds no technical justification for the assertion that FEC Codes / Interleaving, under any circumstance, does in fact prevent interference to data transmissions.

[4] Letter dated Feb, 26, 2004 from Frederick R. Wentland, Associate Administrator, Office of Spectrum Management, NTIA, to John B. Muleta, Chief, Wireless Telecommunications Bureau (NTIA Cover Leter).

[5] The JSC recommended FEC code / Block Interleaving consumes in certain circumstances between 60-70% of the channel throughput for error correction.

RF Neulink agrees with the Dorr Engineering's conclusions that FEC Coding and Block Interleaving is not an effective engineering solution to prevent AIS interference. In an attempt to validate our conclusions, we have reviewed the JSC report, the NTIA's comments and the Commissions' tentative conclusion looking for the engineering justification supporting the claim that a FEC code and Block Interleaving scheme will "prevent interference to VPC data transmissions"[6] and in fact cannot find such justification in this record. Specifically, we cannot find evidence that such an approach is effective, much less practical for a wide area wireless data system.

Designation of Channels 87B and 88B for AIS vs. two narrowband offset channel pairs

It is not clear how the Commission concludes that assigning channels 87B and 88B for AIS "should not have an adverse effect on MariTEL's use of its VPC channels to a materially greater extent, if at all, than would designation of two narrowband offset channel pairs". The test results from Dorr Engineering directly correlate greater frequency separation between the AIS transmitter and data receiver with improved receiver performance. Our testing clearly shows the exponential benefit to data receiver performance when the AIS transmitter is separated further away in frequency, such as when AIS is operating in duplex vs. simplex mode. In addition, a variety of design options such as duplexers or other filtering techniques are cost effective options for deploying wide area systems when transmitters and receivers are sufficiently separated in frequency. These same design options are not technically or financially feasible when deploying systems when transmitters and receivers are very close in proximity[7].

Based on our test results and operations experience, RF Neulink disagrees with the Commissions tentative conclusion that assigning channels 87B and 88B for AIS will not have an distinct adverse effect on MariTEL's operations and cost of doing business as compared with the assignment of duplex channel pairs

Alternative Solution

While our engineering analysis fundamentally differs with the Commissions tentative conclusions that 1) a FEC code and Block Interleaving scheme can prevent AIS interference and 2) simplex AIS will not effect a data system materially greater than duplex channels; RF Industries has developed an alternative solution which allows the Commission to assign 87B and 88B for AIS with comparatively minimum impact to the uses of adjacent and adjoining channels on the same vessel. This solution has two components and applies in the event that both AIS and other maritime communication devices are located on the same vessel.

1) The Commission should require that receivers using channels in close proximity to AIS transmitters install a filtering system or other scheme to minimize the impact of high AIS power into the receiver.

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[6] AIS NPRM ¶ 47

[7] System operations with TX and RX closer than roughly 200kHz are more costly to deploy and operate as compared with systems with less than 200kHz separation between TX and RX.

2) The Commission should require that AIS transmitters install a band-pass filter or other scheme to minimize the impact of spurious emissions to adjacent channel users.

This alternative solution is not without challenges, including the need for additional installation guidelines, coordination and the establishment of new requirements on users of channels in close proximity to AIS transmissions. This solution, however, can be readily implemented and is technically superior to the Commissions' tentative conclusion suggesting other users of the maritime spectrum to adopt technology which has not been proven to prevent AIS interference. .

Sincerely,

Robert White
RF Industries

DESI

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DATE: December 2, 2004

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RE: Results of Testing NL6000 Data Transceiver with AIS Interference

EXECUTIVE SUMMARY

This report contains results obtained from testing the Neulink NL6000 receiver in the presence of AIS interference. These tests were conducted by DESI in San Marcos, California. DESI (www.dorrengineering.com) specializes in wireless modem[1] and protocol[2] design and was responsible for development of the NL6000 product.

In February 2004 the Joint Spectrum Center (JSC) released the document SC-PR-04-007 which analyzed the effects of AIS interference on a VHF receiver. This report concluded that "The use of FEC codes and block interleaving should allow it (the digital receiver) to operate normally in the presence of AIS transmissions." The report also suggested that a (31, 23) Reed-Solomon code with a depth-16 interleaver would alleviate interference problems, but did not provide justification or engineering analysis to support this suggestion. The report also did not mention the impact to data throughput when a large interleaver is used to send small messages such as acknowledgements.

The JSC report also recommended further analysis: "the effect of Rayleigh fading, multipath and existing systems, such as pager systems and NOAA weather transmissions on the PC receiver" should be examined. We agree with this suggestion because it is extremely difficult to estimate the performance of a FM limiter/discriminator receiver using FEC/interleaving in the presence of multipath fading. This report continues the work of the JSC by actually measuring the

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[1] Choosing the Right Modem for a Mobile Radio Network – Mobile Radio Technology Magazine, Part 1: August 1991, Part 2: September 1991.

[2] How Mobile Radio Fading Affects Data Transmission – Mobile Radio Technology Magazine, Part 1: November 1995, Part 2: August 1996.

performance of the NL6000 with AIS interference. The tests included two of the NL6000's normal configuration options: CRC only, and (31, 19) Reed-Solomon coding with interleave depth 6. The tests also used an interleave depth of 16 as suggested by JSC.

We conclude that FEC/interleaving techniques are not an effective engineering solution to mitigate AIS interference. Our test results show that increased coding does not mitigate AIS interference and associated marginal gains from increased coding do not justify the resulting throughput loss and latency increase to the data system compared to the case where data protocols are optimized for performance in a normal RF fading environment in the absence of AIS interference. Effective operation of a data device in close proximity to an AIS transmitter on a vessel must involve either: 1) Minimizing the AIS power input into the data receiver through antenna separation or filtering techniques or 2) Developing new unique technology that specifically mitigates the characteristics of AIS interference.

TEST SETUP

The basic test setup is shown in figure 1 below.

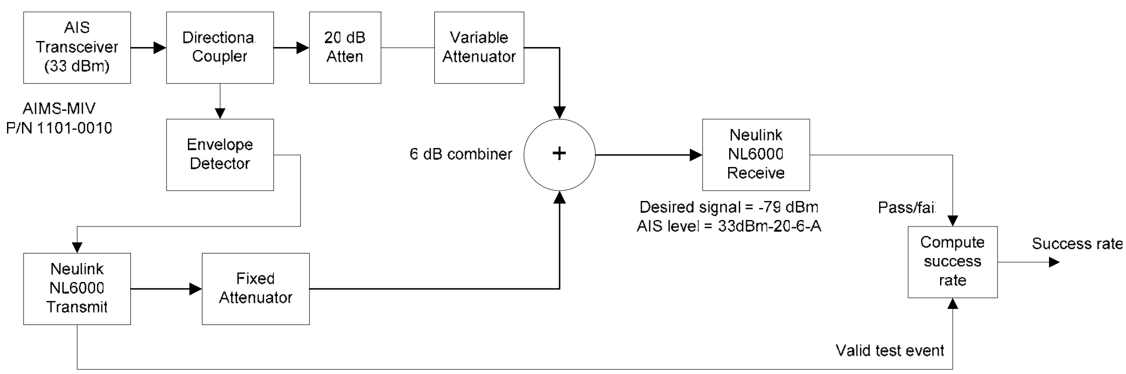

Figure 1 – Test setup

The objective of this test setup is to test packet transmission success or failure when and only when packets are affected by the AIS data burst. This is done by transmitting 1000 data packets from an NL6000 transmitter to a separate NL6000 receiver. The payload size for all packets was 174 bytes.

Since the AIS unit transmits pulses asynchronously to the NL6000, one of three outcomes may occur when the AIS unit transmits. The first outcome is that the AIS burst will begin and end in between NL6000 transmissions. In this case data transmission is unaffected. The second outcome is that the AIS transmission will occur entirely within the NL6000 transmission. In this case, data transmission will be corrupted if the AIS signal is sufficiently strong. The third outcome is that the AIS transmission will overlap the NL6000 transmission. In this case, the data transmission may be corrupted depending on the strength of the AIS transmission and the NL6000 data protocol.

The RF envelope detector and special software in the NL6000 transmitter were used to identify collision events. The criteria for a collision is that the AIS transmitter is activated anywhere in the area from 15 ms after the NL6000 preamble begins to when the NL6000 un-keys. Note that this criterion declares collision events even with the slightest overlap.[3]

The desired signal into the NL6000 receiver was set to -79 dBm. This level was chosen because it is significantly higher than the level of any radiated signal between the NL6000 transmitter and receiver. As a result, radiated signals did not affect the tests.

Tests were done with various frequency spacing between the AIS transmitter and the NL6000. Tests were also done using different combinations of Forward Error Correction (FEC) and interleaving in the NL6000.

1	162.0000 MHz	+25KHz	test 4, 5, 6
2	161.9500 MHz	-25 KHz	test 10, 11, 12
3	161.9000 MHz	-75 KHz	test 16,17,18
4	161.8500 MHz	-125 KHz	test 22,23,24
5	161.8000 MHz	-175 KHz	test 1, 2, 3
6	161.4750 MHz	-500 KHz	test 19, 20, 21
7	160.9750 MHz	1 MHz	test 13, 14, 15
8	156.2500 MHz	5.725 MHz	test 7, 8, 9

Table 1 – Test frequencies and offsets

DISCUSSION OF EXPECTED RESULTS

The NL6000 uses four-level Frequency Shift Keying (FSK) for data transmission. The bit rate is 22.05 KB/S and the peak FM deviation is approximately 4 KHz. A rough estimate of the performance in a non-faded environment can be obtained by treating the system as an FM transmission system with a modulation index of approximately 2. For this case the threshold SNR at the discriminator input is approximately 12 dB. In other words if the post-IF SNR exceeds 12 dB, the received signal will be meaningful; below 12 dB, it will be extremely noisy. If we further assume that the AIS interference appears as noise, a Signal to Interference Ratio (SIR) of greater than 12 dB exceeds threshold. The model can be made more accurate by assuming that at about 16 dB SIR the modem will begin to take errors and at 6 dB SIR the modem will fail entirely. As a result, we would expect a protocol with error detection only to fail at approximately 16 dB SIR, and we would expect all protocols with FEC to fail at 6 dB. Protocols with low-redundancy FEC will fail closer to 16 dB. Those with high-redundancy will fail closer to 6 dB.

Ignoring the fact that the carrier is modulated, we can estimate the maximum AIS signal level. Using -98 dBm for the desired signal and 70 dB selectivity for the NL6000 suggests that with error detection only the maximum level of the interferer is -98dBm – 16dB + 70dB = -44 dBm.

[3] For this criterion, NL6000 transmissions will be successful in many overlap cases which are identified as collisions; especially when FEC interleaving is used. An alternative criterion for collision could be that the AIS transmission is completely contained in the NL6000 transmission. Under this criterion NL6000 transmissions will sometimes fail when no collision is identified.

The actual level will probably be lower than this because the AIS signal is modulated. The modulation is 9600 bps GMSK. Examination of the spectrum (figure B-3 of the JSC report) shows that the BT product is about 0.5. The 99% occupied bandwidth for this modulation is 9984 Hz.[4] Selectivity measurements using EIA/TIA 603 use an occupied (Carson) bandwidth of 6000 Hz for the interferer. As a result, we expect the radio to have less selectivity than 70 dB which will reduce the acceptable AIS level.

This is valid for both pulsed and continuous interference because with CRC only, a single error will disqualify the packet.

When FEC and interleaving are used, the pulse length becomes important. The (31,6) Reed-Solomon code combined with a depth 6 interleaver (as used in the mobile data mode of the NL6000) can correct error bursts of 8.16 ms. Therefore if the combination of the interference pulse width and the recovery time of the receiver is less than 8.16 ms, the data packet will be received regardless of the interferer level. If the interleaver is increased to depth 16 (as suggested by the JSC report) the time is extended to 21.7 ms. However since the duration of the AIS pulse is at least 25 ms, neither code would be able to correct the entire burst and we conclude that if the interferer exceeds -98dBm – 6dB + 70 dB = -34 dBm, packets will fail.

In summary, we expect that using CRC-only; the interferer level must be less than -44 dBm for successful packet transmission. With the depth 6 and depth 16 interleaver, packets will begin to fail at interference levels between -44 dBm and -34 dBm.

INTERPETATION AND PROCESSING OF THE RAW TEST RESULTS

The raw test data was used to compute the interfering signal strength from the AIS transmitter which causes the NL6000 to lose 50% of the packets transmitted during a collision as defined above when the desired signal strength into the NL6000 is -98 dBm. The 50% metric was selected because it was the most reliable measurement. In general, when the AIS signal power was 10 dB above the 50% point all transmissions from the NL6000 failed and at 10 dB below the 50% point all transmissions from the NL6000 were successful.

The steps for converting the raw data to the 50% point are outlined below.

The raw data was displayed by plotting the packet error rate as a function of the AIS attenuation. The packet error rate was the number of unsuccessful packets divided by the number of detected collisions. Data points for these curves have a large variance, and the curves are therefore not smooth. The reason for this is that packet success or failure depends on the location of the interfering signal in temporal relation to the NL6000 burst, and the actual length of the AIS transmission which was sometimes observed to be longer than 25 ms. Since the AIS transmitter transmits only once per 10 seconds, averaging over all of these events would take an impractically long time.

The curves became especially noisy when the expected packet error rate was high. The reason for this was that with strong AIS interference, packets were still received because the collisions either occurred in partial overlap areas or on overlapping boundaries between interleaved codeblocks. It was also difficult to get good measurements when the expected error rate was low. The reason for this is that even with interleaving and FEC the signal is susceptible during the preamble and sync word which are not interleaved. As a result, the lowest variance measurements were in the area of 50% packet success and it was therefore used as our metric.

[4] GMSK Modulation for Mobile Telephony, Murota, Hirade, 1981

The attenuation used was then converted to an interfering signal strength into the NL6000 receiver. Referring to figure 1 above, the interferer level is 7 dBm – A where A is the attenuator setting in dB.

The final step is to reduce the interference level by 19 dB to account for the difference between our -79 dBm test signal and the -98 dBm nominal desired receive level into the NL6000.

A representative plot showing packet success rate as a function of the AIS Interference level is shown below:

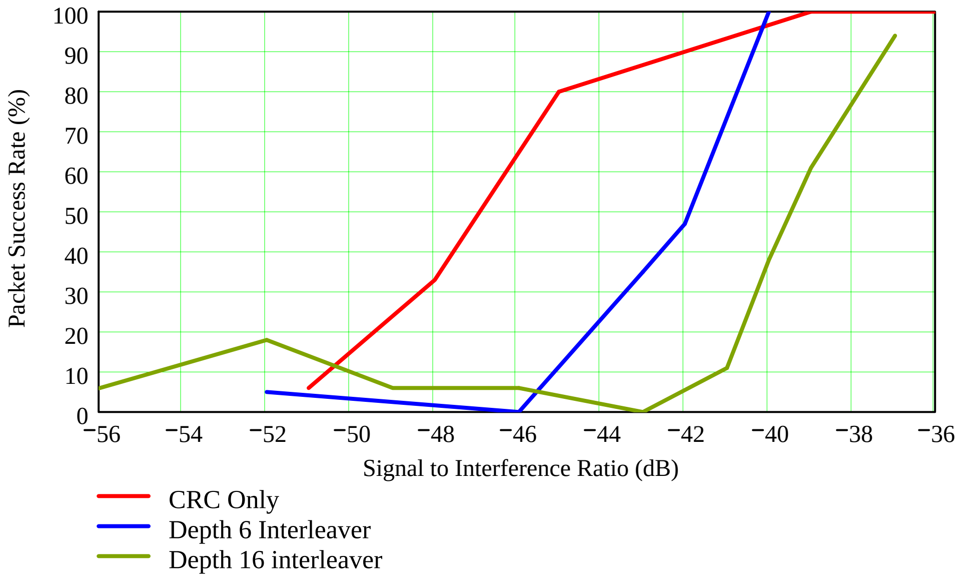

Figure 2 – Packet success rate vs. received AIS signal level. Desired signal level is -98 dBm

COMPILED RESULTS - 50% PACKET SUCCESS PERFORMANCE

The plot below shows the level of AIS interference which will cause the NL6000 to receive 50% of transmitted packets during collisions when the level of the desired signal is -98 dBm. This data is extrapolated from the data taken using a -79 dBm signal from the NL6000 as described above.

	162.000 (+25K)	161.950 (-25K)	161.900 (-75K)	161.850 (-125 K)	161.800 (-175K)	161.475 (-500K)	160.975 (-1 M)	156.250 (-5.725M)
CRC	-64.1 dBm	-66.6 dBm	-57 dBm	-44.33 dBm	-38.58 dBm	-41.2 dBm	-46.8 dBm	-25.9 dBm
INT6	-53.4 dBm	-43.7 dBm	-39.8 dBm	-38.9 dBm	-35.6 dBm	-31.42 dBm	-41.8 dBm	-16.5 dBm
INT 16	-45.8 dBm	-42.0 dBm	-38 dBm	-36.4 dBm	-29.6 dBm	-30.7 dBm	-39.6 dBm	-12 dBm

Table 2 – AIS interference level for 50% packet success

The table below uses free-space path loss to compute the distance between a 12 Watt AIS antenna and the NL6000 antenna. The first number is the distance at which all NL6000 packets would be unsuccessful given a collision. The second number in each cell is the distance for 50% packet loss given a collision. The third number is the distance where the NL6000 would not be affected by AIS transmissions. For this table we use plus and minus 10 dB for the 100% failure and 0 % failure points.

	162.000 (+25K)	161.950 (-25K)	161.900 (-75K)	161.850 (-125 K)	161.800 (-175K)	161.475 (-500K)	160.975 (-1 M)	156.250 (-5.725M)
CRC	5.5 mi 17.3 mi 54.7 mi	7.3 mi 23.1 mi 73 mi	2.4 mi 7.6 mi 24.2 mi	0.56 mi 1.8 mi 5.6 mi	0.28 mi 0.9 mi 2.9 mi	0.39 mi 1.2 mi 3.9 mi	0.75 mi 2.4 mi 7.5 mi	351 ft 0.21 mi 0.66 mi
INT6	1.61 mi 5.1 mi 16.1 mi	0.54 mi 1.7 mi 5.4 mi	0.33 mi 1.0 mi 3.3 mi	0.3 mi 0.95 mi 3.0 mi	1086 ft 0.65 mi 2.0 mi	0.13 mi 0.40 mi 1.3 mi	0.42 mi 1.3 mi 4.2 mi	120 ft 382 ft 1207 ft
INT 16	0.66 mi 2.1 mi 6.6 mi	0.44 mi 1.4 mi 4.4 mi	0.27 mi 0.86 mi 2.7 mi	0.23 mi 0.72 mi 2.3 mi	551 ft 0.33 mi 1.0 mi	0.12 mi 0.37 mi 1.2 mi	0.33 mi 1.0 mi 3.3 mi	72 ft 228 ft 720 ft

Table 3 – Distance from AIS antenna to NL6000 antenna for 100%, 50%, 0% packet failure

DISCUSSION OF MEASURED RESULTS

The simple calculations above suggested that the CRC-only mode would lose packets at interference levels of -44 dBm if the selectivity of the radio was 70 dB. In the two channels above and below the AIS transmitter the 50% points were 64.1 and 66.1 respectively which is below our estimate by 21.1 dB. This is due to the 9600 bps GMSK modulation. It may also be due to spectral splattering when the AIS unit keys and un-keys.

At -175K, the 50% point was -38.58 dBm which is 5.4 dB above our estimate which is reasonable. At -5.725 MHz the 50% point is -25.9 dBm which is 18.1 dB above our estimate. We believe that the NL6000 receiver has more than 70 dB of selectivity at this large offset. In summary, our measured results appear reasonable compared to our predictions so we believe that the equipment was set up properly and the measurements were done correctly.

Our predictions estimated that in the FEC interleaved modes failures would occur between -44 dBm and -34 dBm. Our (31,19) Reed-Solomon code is neither overly strong nor weak, so we roughly estimate the level as around -39 dBm. As before in the channels immediately adjacent to the AIS transmitter the AIS level is lower than predicted, in the -175 KHz offset region the estimate is fairly close, and at the -5.725 MHz frequency offset the allowable AIS level is higher than expected. This reinforces our belief that the measurements were taken correctly.

COMMENTS ON THE JSC REPORT

Information in the JSC report was based on the COSAM model which is likely much more accurate than the simple calculations used to estimate performance in this report. However, the JSC used BER as the performance criteria instead of the packet success probability, and used 5% packet loss as the criteria for acceptability. It is extremely difficult to convert FEC code parameters to a packet error rate in a Rayleigh fading environment; it is usually done with simulation. The NL6000 uses the (31, 19) code with a depth six interleaver because this combination provides good performance with fading. When fading is present the modem will sometimes still lose 5% of the data packets, but under static conditions, the modem runs nearly error-free. Therefore, the best approach is to use FEC interleaving for fading rather than for AIS mitigation.

The JSC report concluded (page 3-2) that “The predicted PC digital receiver performance degradation is sufficient to impact the PC receiver in both the single and multiple AIS transmitter case when FEC is not employed. The use of FEC codes and block interleaving in the receiver should allow it to operate normally in the presence of AIS transmissions.”

Our measured data indicates that an AIS transmitter operating at 12 Watts and located on the same ship as an NL6000 radio receiver will corrupt 174-byte payload data transmissions intended for the NL6000 on the ship when the nominal RSL for the NL6000 is -98 dBm. Contrary to the JSC report, 50% of NL6000 data packets will fail if the AIS and NL6000 antennas are spaced less than 1.4 miles apart and either channel adjacent to the AIS transmitter is used. If the AIS transmit frequency and NL6000 receive frequency are offset by 175 KHz, then 50% of packets will be lost if the antennas are spaced by about 1740 ft.

In the JSC multiple transmitter case, four of 18 ships were within 1.4 miles of the origin ship and two more were very close to 1.4 miles. If the NL6000 on the origin ship is tuned to an adjacent channel from the AIS transmitters then AIS transmissions from any of the four nearby ships would corrupt data packets intended for the origin ship.

Based on our measured data we disagree with the JSC finding that FEC and interleaving will allow the NL6000 to operate normally in the presence of single AIS transmissions. We also disagree with the JSC finding that FEC and interleaving will allow the NL6000 to operate normally in the presence of multiple transmissions.

IMPACT OF AIS TRANSMISSIONS ON A PACKET DATA SYSTEM

The tests showed that the coding/interleaver combination suggested by the JSC provided some improvement over the coding/interleaver combination normally used by the NL6000, but it did not eliminate interference problems. Specifically when the AIS transmitter is located on a ship which also has an NL6000 receiver which is receiving data packets from a presumably fixed location at -98 dBm, the data transmissions will be corrupted when the AIS transmitter activates.

In the discussion below, the inbound channel is the channel used for sending data from ship to shore. The outbound channel is used to send data from shore to ship.

In this section we consider the effect of AIS transmission on a data packet with a 500 byte payload. The packet uses the (31,19) Reed-Solomon code. Interleaving is used to mitigate Rayleigh (multipath) fading, but will not correct packets corrupted by the local AIS transmissions. The data rate is 22,050 bps and the approximate packet length is 350 ms when the modem’s preamble, sync word, and header are included. When the AIS transmitter and base station operate asynchronously, and the AIS transmitter transmits once in 10 seconds, the probability of corruption is 3.5%. If the AIS transmitter transmits every two seconds, the probability is 17.5%.[5]

Packet data systems typically consist of a number of mobile units which communicate with a central base station presumably located at a fixed site and visible to all mobiles. Mobiles generate traffic such as email messages, position reports, etc autonomously thereby forming a random access network. In other words, mobiles use the inbound frequency on demand. Outbound transmissions send specific messages to mobiles (such as e-mail), acknowledge inbound messages, and broadcast data intended for all mobiles (such as weather).

Throughput on the outbound channel will be affected because packets are destroyed by the local AIS transmission. When the AIS transmits at the two second rate, the throughput loss will be at least 17.5%. Additional throughput loss will occur at the transport layer because of the failure at the phy/mac/link layer.

AIS interference will also affect the performance of the inbound channel. This is primarily due to inbound retransmissions resulting from the loss of outbound acknowledgements to previous inbound messages. In the high AIS rate, 17.5% of the outbound acknowledgements will be missed by the ship, and the ship will re-send the original message on the inbound channel. A basic characteristic of random access networks[6] is that as the inbound throughput requirement increases, first time success probability decreases and network latency increases. This causes the network to appear unreliable and slow to the user.

The largest impact occurs when the base is broadcasting a message such as a weather report to the ships. In this case, the mobiles do not acknowledge the base station. If a packet is missed then the mobile must wait for the base station to repeat the entire message. We consider a 100 KB message broadcast to all the mobiles. This message consists of 200 packets of 500 bytes apiece. Table 4 below shows the probability of receiving all packets within a specified number of transmissions. The table shows that the message must be transmitted a total of six times for 99% assurance that it will be received by all ships. Sending 5 re-transmissions will reduce broadcast throughput by 83%.

Transmissions	Elapsed Time	2 Second AIS	10 Second AIS
1	70 Sec	0 %	0.08%
2	140 Sec	20%	78%
3	210 Sec	34%	99%
4	280 Sec	83%	99.97%
5	350 Sec	97%	> 99.97%
6	420 Sec	99%	> 99.97%

Table 4 – Probability of receiving a 100 k-byte message within a specified number of repeats

5 If there are other ships in close proximity, their AIS transmitters will affect outbound data packets intended for other ships which raises probability of failure. For simplicity we use the 17.5% figure.

6 Hammond and O'Reilly, Performance Analysis of Local Computer Networks, Addison Wesley, 1988

CONCLUSIONS

This report contains results obtained from testing the Neulink NL6000 receiver in the presence of AIS interference. These tests were conducted by DESI in San Marcos, California. DESI (www.dorrengineering.com) specializes in wireless modem and protocol design and was responsible for development of the NL6000 product.

In February 2004 the Joint Spectrum Center (JSC) released the document SC-PR-04-007 which analyzed the effects of AIS interference on a VHF receiver. This report concluded that "The use of FEC codes and block interleaving should allow it (the digital receiver) to operate normally in the presence of AIS transmissions." The report also suggested that a (31,23) Reed-Solomon code with a depth-16 interleaver would alleviate interference problems, but did not provide justification or engineering analysis to support this suggestion. The report also did not mention the impact to data throughput when a large interleaver is used to send small messages such as acknowledgements.

The JSC report also recommended further analysis: "the effect of Rayleigh fading, multipath and existing systems, such as pager systems and NOAA weather transmissions on the PC receiver" should be examined. We agree with this suggestion because it is extremely difficult to estimate the performance of a FM limiter/discriminator receiver using FEC/interleaving in the presence of multipath fading. This report continues the work of the JSC by actually measuring the performance of the NL6000 with AIS interference. The tests included two of the NL6000s normal configuration options: CRC only and (31,19) Reed-Solomon with interleave depth 6. The tests also used an interleave depth of 16 as suggested by JSC.

Our measured data indicates that an AIS transmitter operating at 12 Watts and located on the same ship as an NL6000 radio receiver will corrupt 174-byte payload data transmissions intended for the NL6000 on the ship when the nominal RSL for the NL6000 is -98 dBm. Contrary to the JSC report, 50% of NL6000 data packets will fail if the AIS and NL6000 antennas are spaced less than 1.4 miles apart and either channel adjacent to the AIS transmitter is used. If the AIS transmit frequency and NL6000 receive frequency are offset by 175 KHz, then 50% of packets will be lost if the antennas are spaced by about 1740 ft.

The NL6000 provides three data protocol options allowing the service provider to select the best configuration for his RF environment. The first mode uses CRC only, the second uses the (31,19) Reed-Solomon code, and the third uses the (31,19) Reed-Solomon code with a interleaver depth of six. The interleaver depth of six was chosen because fading simulations show it is the shortest interleaver which eliminates the effect of vehicle speed on data packet performance. Increasing the interleaver further provides little additional fading benefit, but throughput decreases because many short messages, such as acknowledgements, are shorter than the minimum interleaver block size resulting in dummy bits being sent over the channel. Increasing the interleaver depth to correct both the 25 ms and 100 ms AIS bursts would significantly increase the minimum packet transmission and seriously degrade throughput.

The tests showed that the depth 16 coding/interleaver combination suggested by the JSC provided some improvement over the depth six combination normally used by the NL6000. The reason for this is that more packets were corrected when the AIS interference pulse partially overlapped the NL6000 transmission. However when the AIS pulse was fully contained within the NL6000 transmission, none of the coding/interleaver combinations could correct the AIS error bursts.

AIS interference will increase latency and decrease throughput of a packet data system which results in dissatisfaction for the customer and reduced billing for the operator. Though the interference affects the outbound (shore-to-ship) channel only, the inbound channel will also be affected because of retransmissions due to corrupted outbound acknowledgements.

The greatest degradation from AIS interference occurs with outbound broadcast messages which are not acknowledged by the ships. In this case, a 100 K-byte message would have to be sent six times for 99% probability of successful reception by each ship thereby reducing the broadcast throughput by 83%.

We conclude that while FEC/interleaving techniques could be used to correct error bursts caused by AIS transmissions of 25 or 100 ms, but the resulting throughput loss and latency increase would significantly degrade the quality of a maritime packet data service compared to the case where there was no AIS interference and data protocols intended for optimum performance in a multipath fading environment were used. Effective operation in close proximity to an AIS transmitter on a vessel must involve either: 1) Minimizing the AIS power input into the data receiver through antenna separation or filtering techniques or 2) Developing new unique technology that specifically mitigates the characteristics of AIS interference.

RAW TEST DATA

Test ID	AIS TX Freq (MHz)	NL6000 Freq. (MHz)	Coding	Atten. (dB)	Lost/tot
1-40	161.975	161.8000	CRC	40	0/21 | 0%
1-36	161.975	161.8000	CRC	36	4/19 | 21%
1-32	161.975	161.8000	CRC	32	3/15 | 20%
1-28	161.975	161.8000	CRC	28	6/16 | 37%
1-22	161.975	161.8000	CRC	22	9/11 | 82%
1-19	161.975	161.8000	CRC	19	9/10 | 90%
2-32	161.975	161.8000	INT 6	32	0/23 | 0%
2-27	161.975	161.8000	INT 6	27	2/25 | 8%
2-22	161.975	161.8000	INT 6	22	11/16 | 69%
2-18	161.975	161.8000	INT 6	18	10/14 | 71%
2-15	161.975	161.8000	INT 6	15	16/20 | 80%
2-12	161.975	161.8000	INT 6	12	17/18 | 94%
3-42	161.975	161.8000	INT 16	42	5/24 | 21%
3-39	161.975	161.8000	INT 16	39	2/20 | 10%
3-36	161.975	161.8000	INT 16	36	4/18 |22%
3-33	161.975	161.8000	INT 16	33	2/13 | 15%
3-30	161.975	161.8000	INT 16	30	1/22 | 4.5%
3-27	161.975	161.8000	INT 16	27	1/19 | 5.2%
3-22	161.975	161.8000	INT 16	22	2/18 | 11%
3-18	161.975	161.8000	INT 16	18	7/16 | 44%
3-17	161.975	161.8000	INT 16	17	18/24 | 75%
3-15	161.975	161.8000	INT 16	15	10/14 | 71%
3-12	161.975	161.8000	INT 16	12	16/17 | 94%
4-72	161.975	162.0000	CRC	72	0/20 | 0%

Test ID	AIS TX Freq (MHz)	NL6000 Freq. (MHz)	Coding	Atten. (dB)	Lost/tot
4-64	161.975	162.0000	CRC	64	5/16 | 31%
4-70	161.975	162.0000	CRC	70	0/18 | 0%
4-64	161.975	162.0000	CRC	64	4/12 | 33%
4-58	161.975	162.0000	CRC	58	5/12 | 42%
4-52	161.975	162.0000	CRC	52	7/14 | 50%
4-46	161.975	162.0000	CRC	46	19/20 | 95%
4-43	161.975	162.0000	CRC	43	10/13 | 77%
4-40	161.975	162.0000	CRC	40	7/8 | 88%
4-37	161.975	162.0000	CRC	37	6/7 | 86%
4-34	161.975	162.0000	CRC	34	8/12 | 66%
4-31	161.975	162.0000	CRC	31	12/12 | 100%
5-58	161.975	162.0000	INT 6	58	0/18 | 0%
5-52	161.975	162.0000	INT 6	52	4/17 | 24%
5-46	161.975	162.0000	INT 6	46	0/19 | 0%
5-43	161.975	162.0000	INT 6	43	3/15 | 20%
5-40	161.975	162.0000	INT 6	40	17/22 | 77%
5-37	161.975	162.0000	INT 6	37	18/25 | 72%
5-34	161.975	162.0000	INT 6	34	15/23 | 65%
5-31	161.975	162.0000	INT 6	31	20/21 | 95%
5-28	161.975	162.0000	INT 6	28	12/15 | 80%
5-25	161.975	162.0000	INT 6	25	12/15 | 80%
5-22	161.975	162.0000	INT 6	22	13/20 | 65%
6-52	161.975	162.0000	INT 16	52	0/20 | 0%
6-46	161.975	162.0000	INT 16	46	0/19 | 0%
6-40	161.975	162.0000	INT 16	40	2/16 | 12%
6-37	161.975	162.0000	INT 16	37	3/13 | 23%

Test ID	AIS TX Freq (MHz)	NL6000 Freq. (MHz)	Coding	Atten. (dB)	Lost/tot
6-34	161.975	162.0000	INT 16	34	7/15 | 47%
6-31	161.975	162.0000	INT 16	31	16/25 | 64%
6-28	161.975	162.0000	INT 16	28	18/23 | 78%
6-25	161.975	162.0000	INT 16	25	16/21 | 76%
6-23	161.975	162.0000	INT 16	23	17/19 | 89%
7-27	161.975	156.250	CRC	27	0/14 | 0%
7-21	161.975	156.250	CRC	21	0/20 | 0%
7-15	161.975	156.250	CRC	15	3/16 | 19%
7-12	161.975	156.250	CRC	12	7/10 | 70%
7-10	161.975	156.250	CRC	10	14/15 | 93%
8-15	161.975	156.250	INT 6	15	0/18 | 0%
8-12	161.975	156.250	INT 6	12	0/19 | 0%
8-9	161.975	156.250	INT 6	9	3/22 | 14%
8-6	161.975	156.250	INT 6	6	4/10 | 40%
8-3	161.975	156.250	INT 6	3	13/21 | 62%
8-0	161.975	156.250	INT 6	0	20/26 | 77%
9-12	161.975	156.250	INT 16	12	0/20 | 0%
9-9	161.975	156.250	INT 16	9	4/22 | 18%
9-6	161.975	156.250	INT 16	6	5/16 | 31%
9-3	161.975	156.250	INT 16	3	5/20 | 25%
9-0	161.975	156.250	INT 16	0	3/20 | 15%
10-76	161.975	161.950	CRC	76	0/8 | 0%
10-70	161.975	161.950	CRC	70	6/12 | 50%
10-64	161.975	161.950	CRC	64	5/14 | 36%

Test ID	AIS TX Freq (MHz)	NL6000 Freq. (MHz)	Coding	Atten. (dB)	Lost/tot
10-58	161.975	161.950	CRC	58	3/10 | 30%
10-52	161.975	161.950	CRC	52	4/11 | 36%
10-46	161.975	161.950	CRC	46	11/14 | 79%
10-40	161.975	161.950	CRC	40	9/17 | 53%
10-39	161.975	161.950	CRC	39	7/9 | 77%
10-36	161.975	161.950	CRC	36	15/16 | 94%
10-33	161.975	161.950	CRC	33	13/14 | 93%
11-40	161.975	161.950	INT 6	40	0/19 | 0%
11-37	161.975	161.950	INT 6	37	4/21 | 19%
11-34	161.975	161.950	INT 6	34	5/14 | 36%
11-31	161.975	161.950	INT 6	31	12/21 | 57%
11-28	161.975	161.950	INT 6	28	13/17 | 76%
11-25	161.975	161.950	INT 6	25	17/19 | 89%
12-40	161.975	161.950	INT 16	40	0/21 | 0%
12-34	161.975	161.950	INT 16	34	1/21 | 5%
12-28	161.975	161.950	INT 16	28	11/16 | 69%
12-25	161.975	161.950	INT 16	25	16/19 | 84%
12-22	161.975	161.950	INT 16	22	10/14 | 71%
13-39	161.975	160.975	CRC	39	1/16 | 6%
13-36	161.975	160.975	CRC	36	4/12 | 33%
13-33	161.975	160.975	CRC	33	4/5 | 80%
13-27	161.975	160.975	CRC	27	14/14 | 100%
13-15	161.975	160.975	CRC	15	16/16 | 100%
14-40	161.975	160.975	INT 6	40	1/19 | 5%

Test ID	AIS TX Freq (MHz)	NL6000 Freq. (MHz)	Coding	Atten. (dB)	Lost/tot
14-34	161.975	160.975	INT 6	34	0/21 | 0%
14-31	161.975	160.975	INT 6	31	6/17 | 35%
14-30	161.975	160.975	INT 6	30	9/19 | | 47%
14-28	161.975	160.975	INT 6	28	19/19 | 100%
15-46	161.975	160.975	INT 16	46	0/21 | 0%
15-40	161.975	160.975	INT 16	40	2/11 | 18%
15-37	161.975	160.975	INT 16	37	1/17 | 6%
15-34	161.975	160.975	INT 16	34	1/17 | 6%
15-31	161.975	160.975	INT 16	31	0/25 | 0%
15-29	161.975	160.975	INT 16	29	2/17 | 11%
15-28	161.975	160.975	INT 16	28	8/21 | 38%
15-27	161.975	160.975	INT 16	27	11/18 | 61%
15-25	161.975	160.975	INT 16	25	16/17 | 94%
16-67	161.975	161.900	CRC	67	0/19 | 0%
16-61	161.975	161.900	CRC	61	2/17 | 12%
16-55	161.975	161.900	CRC	55	4/13 | 31%
16-52	161.975	161.900	CRC	52	6/12 | 50%
16-49	161.975	161.900	CRC	49	3/9 | 33%
16-46	161.975	161.900	CRC	46	10/19 | 53%
16-43	161.975	161.900	CRC	43	9/16 | 56%
16-40	161.975	161.900	CRC	40	5/17 | 29%
16-37	161.975	161.900	CRC	37	12/14 | 86%
16-34	161.975	161.900	CRC	34	13/15 | 87%
16-31	161.975	161.900	CRC	31	7/8 | 88%
17-60	161.975	161.900	INT 6	60	0/24 |0%

Test ID	AIS TX Freq (MHz)	NL6000 Freq. (MHz)	Coding	Atten. (dB)	Lost/tot
17-54	161.975	161.900	INT 6	54	0/17 | 0%
17-48	161.975	161.900	INT 6	48	0/18 | 0%
17-42	161.975	161.900	INT 6	42	0/20 | 0%
17-36	161.975	161.900	INT 6	36	0/18 | 0%
17-30	161.975	161.900	INT 6	30	1/22 | 5%
17-27	161.975	161.900	INT 6	27	14/22 | 64%
17-26	161.975	161.900	INT 6	26	18/18 | 100%
17-24	161.975	161.900	INT 6	24	21/21 | 100%
18-30	161.975	161.900	INT 16	30	1/13 | 8%
18-27	161.975	161.900	INT 16	27	5/18 | 28%
18-24	161.975	161.900	INT 16	24	10/11 | 91%
18-21	161.975	161.900	INT 16	21	13/19 | 68%
18-18	161.975	161.900	INT 16	18	6/12 | 50%
18-15	161.975	161.900	INT 16	15	7/10 | 70%
18-12	161.975	161.900	INT 16	12	13/16 | 81%
19-40	161.975	161.475	CRC	40	0/13 | 0%
19-34	161.975	161.475	CRC	34	0/20 | 0%
19-31	161.975	161.475	CRC	31	0/12 | 0%
19-28	161.975	161.475	CRC	28	10/12 | 83%
19-25	161.975	161.475	CRC	25	13/14 | 93%
20-34	161.975	161.475	INT 6	34	0/25 | 0%
20-28	161.975	161.475	INT 6	28	2/15 | 13%
20-25	161.975	161.475	INT 6	25	2/24 | 8%
20-22	161.975	161.475	INT 6	22	3/23 | 13%
20-19	161.975	161.475	INT 6	19	12/24 | 50%

Test ID	AIS TX Freq (MHz)	NL6000 Freq. (MHz)	Coding	Atten. (dB)	Lost/tot
20-16	161.975	161.475	INT 6	16	14/17 | 82%
20-13	161.975	161.475	INT 6	13	12/17 | 70%
20-10	161.975	161.475	INT 6	10	17/20 | 85%
21-28	161.975	161.475	INT 16	28	0/21 | 0%
21-22	161.975	161.475	INT 16	22	6/20 | 30%
21-19	161.975	161.475	INT 16	19	10/19 | 53%
21-16	161.975	161.475	INT 16	16	8/10 | 80%
21-13	161.975	161.475	INT 16	13	14/18 | 78%
21-10	161.975	161.475	INT 16	10	15/20 | 75%
22-45	161.975	161.850	CRC	45	1/14 | 7%
22-42	161.975	161.850	CRC	42	2/11 | 18%
22-39	161.975	161.850	CRC	39	6/15 | 40%
22-36	161.975	161.850	CRC	36	6/14 | 43%
22-33	161.975	161.850	CRC	33	8/19 | 42%
22-30	161.975	161.850	CRC	30	9/12 | 75%
22-27	161.975	161.850	CRC	27	11/12 | 92%
22-24	161.975	161.850	CRC	24	17/19 | 89%
23-40	161.975	161.850	INT 6	40	0/19 | 0%
23-34	161.975	161.850	INT 6	34	0/20 | 0%
23-28	161.975	161.850	INT 6	28	0/19 | 0%
23-27	161.975	161.850	INT 6	27	9/18 | 50%
23-25	161.975	161.850	INT 6	25	20/21 | 95%
23-22	161.975	161.850	INT 6	22	14/18 | 77%
24-30	161.975	161.850	INT 16	30	0/16 | 0%

Test ID	AIS TX Freq (MHz)	NL6000 Freq. (MHz)	Coding	Atten. (dB)	Lost/tot
24-27	161.975	161.850	INT 16	27	1/16 | 6%
24-24	161.975	161.850	INT 16	24	8/14 | 57%
24-21	161.975	161.850	INT 16	21	19/22 | 86%
24-18	161.975	161.850	INT 16	18	20/21 | 95%